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Static and Dynamic Retention Assessment of the HGU-56/P Aircrew Integrated Helmet System Equipped with Quick-release ALPHA and Snap- fastener Retention Assemblies



Aircrew Protection Division

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14. ABSTRACT Currently, the HGU-56/P flight helmet chinstrap is fastened by looping the chinstrap webbing through two D-rings. Feedback from the Army aviation community has revealed possible problems with this design. The PM Air Warrior initiated testing of two alternate quick-release fastening mechanisms. The first, the ALPHA buckle, has been successfully used by the British military on their fixed- and rotary-wing helmets. The second is a Pull-the-Dot snap fastener that allows for a quick release. USAARL evaluated the retention qualities of HGU-56/P helmets fitted with both alternate buckle systems. Comparisons were also made between the three buckle types with respect to ease and speed of buckle release. HGU-56/P helmets equipped with the quick-release buckles should provide static and dynamic helmet retention equivalent to that of the standard helmet configured with the double D-ring buckle. Significant ($p < 0.05$) reductions in chinstrap release times were recorded with the use of the ALPHA and snap-fastener buckles as compared to the double D-ring.					
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Introduction

In its current procurement configuration, the HGU-56/P Aircrew Integrated Helmet System (Figure 1) is delivered to the Army with an integrated helmet retention assembly. Included in the retention assembly are the chinstrap, nape pad, and earcup mounting pads. Currently, the mechanism for securing the chinstrap is to loop the chinstrap webbing through a set of two D-rings (Figure 2). Feedback from the U.S. Army and Air Force (Department of the Air Force, 2004) aviation communities has revealed problems with this chinstrap buckle design, including anecdotal reports of aviators having difficulty releasing the double D-ring buckle during or shortly following emergency egress situations.



Figure 1. U.S. Army HGU-56/P Aircrew Integrated Helmet System (Gentex Corporation, Carbondale, PA). Helmet is shown with clear visor deployed and standard retention assembly with double D-ring buckle.

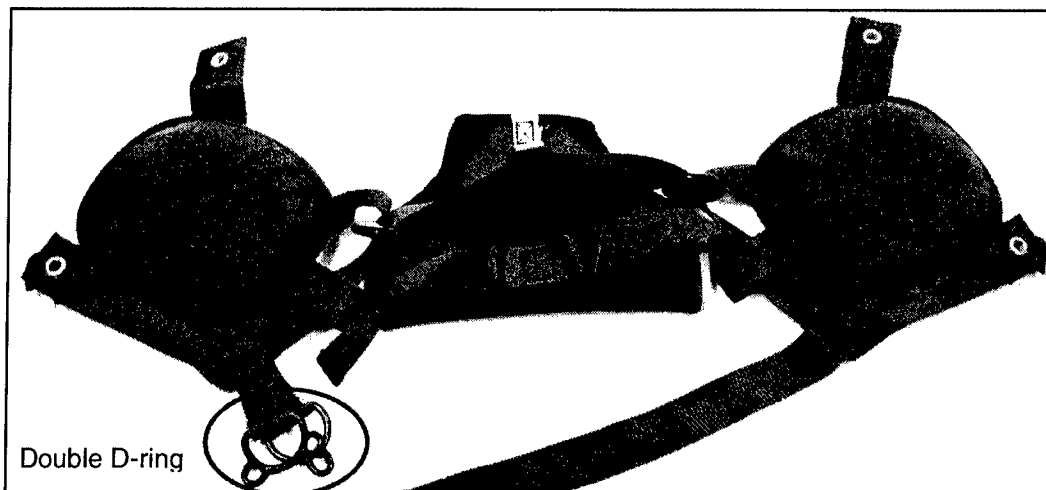


Figure 2. Standard HGU-56/P retention assembly incorporating double D-ring buckle (Gentex Corporation, Carbondale, PA). The Gentex Corporation part number and National Stock Number (NSN) for this retention assembly are 89D7606 and 8415-01-394-8023, respectively.

The Gentex Corporation manufactures and sells two alternate chinstrap buckle systems for use with the HGU-56/P flight helmet. The first is a quick-release buckle used by the British military on their Mark IV (rotary-wing) and Mark X (fixed wing) flight helmet. The British Mark X helmet is commonly referred to as the "ALPHA," and as such, the British-style buckle often is referred to as the ALPHA buckle (Figure 3). The second quick-release buckle is used by the U.S. Coast Guard on their SPH-5CG flight helmets (Figure 4). This system uses the double D-ring configuration for chinstrap adjustment, but also incorporates a Pull-the-Dot snap fastener that allows the chinstrap to be released quickly.

At the request of the Product Manager, Air Warrior (PM-AW), the U.S. Army Aeromedical Research Laboratory (USAARL) evaluated the static and dynamic retention qualities of the two alternate buckle systems and compared their performance to that of the current double D-ring buckle.

As mentioned above, anecdotal reports of aviators experiencing difficulty loosening the standard double D-ring buckle while immersed in sea water provided a partial impetus for this evaluation of quick-release buckles. Therefore, an additional evaluation was conducted to determine if aviators wearing gloves soaked in salt water could successfully manipulate the alternate chinstrap buckles and remove the helmet.

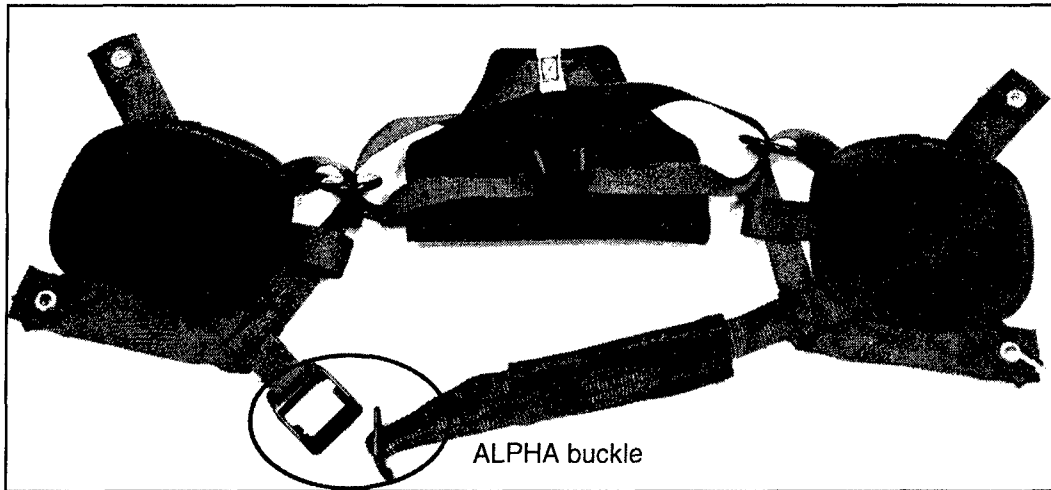


Figure 3. HGU-56/P retention assembly incorporating a quick-release ALPHA buckle (Gentex Corporation, Carbondale, PA). The Gentex Corporation part number for the ALPHA buckle retention assembly is 95D9303-2. No NSN has been assigned to this item.

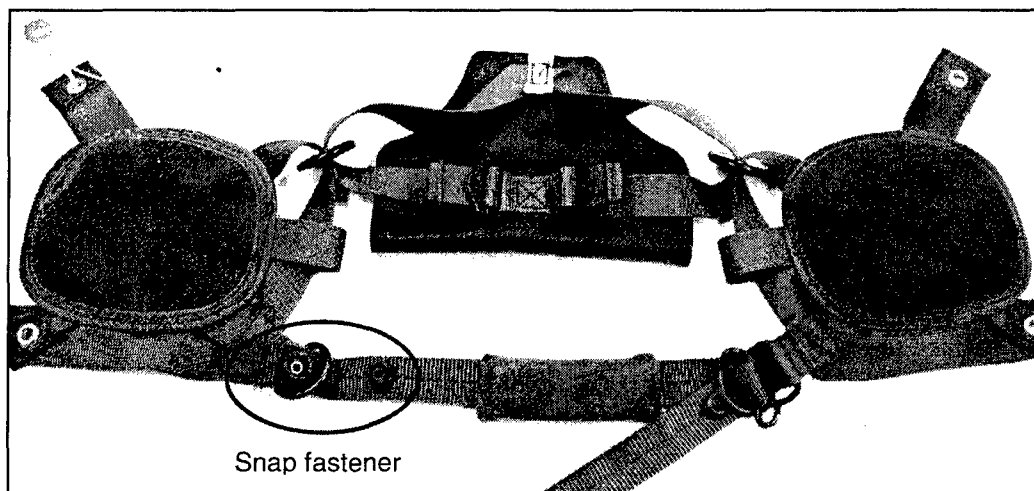


Figure 4. HGU-56/P retention assembly incorporating a quick-release snap-fastener buckle (Gentex Corporation, Carbondale, PA). The Gentex Corporation part number for the snap-fastener retention assembly is 04D11822-2. No NSN has been assigned to this item.

Materials and methods

Experimental equipment

Flight helmets and retention assemblies

Three new medium HGU-56/P flight helmets were used during static chinstrap elongation testing. Each helmet had been previously subjected to blunt impact testing. (The prior testing for blunt-impact performance would have no effect on the static chinstrap elongation measurements.) Three new large HGU-56/P flight helmets were used for dynamic helmet retention tests.

Two ALPHA buckle retention assemblies and two snap-fastener retention assemblies were included in these evaluations. One of each type assembly was used in static chinstrap elongation tests, while the others were used in dynamic helmet retention evaluations.

Compression/tension machine

Chinstrap elongation tests were performed on a quasi-static compression/tension machine (Tinius Olsen, Inc., Horsham, PA) comprised of two vertical worm gears which propel a crosshead vertically within the frame of the machine. Motion of the crosshead relative to the stationary frame was measured using a linear velocity and displacement transducer (LVDT). A load cell attached to the crosshead measured compressive or tensile loads. For chinstrap testing, a headform was mounted to the top of the test frame, and a simulated chin, conforming to the specification of ANSI Z90.1-1979 (1979), was mounted to the load cell on the crosshead (Figure 5). The crosshead was then lowered, placing the chinstrap in tension.

Dynamic Helmet Retention Apparatus (USAARL Mini-sled)

The USAARL-developed mini-sled is a 12-foot long horizontal rail system with a low friction carriage (Figure 6). Mounted on the carriage was a Hybrid III biodynamic neck assembly and a Hybrid II head form. The carriage was positioned at one end of the rail track and accelerated by the impact of a 100-pound pendulum. Varying the pendulum release height and the selection of the interfacing impact spring controlled the acceleration pulse. The carriage was propelled rearward by the impacting pendulum forcing the head and neck into flexion. When helmets are fitted onto the test head form, relative motion occurred as a result of the impact event. This motion was quantified by measuring the helmet's angular displacement relative to the head with a high-speed video system. Carriage motion was arrested, approximately 4 feet from the impact point, with a low friction braking system. These tests were non-destructive, permitting repeated testing of the same helmet assembly.

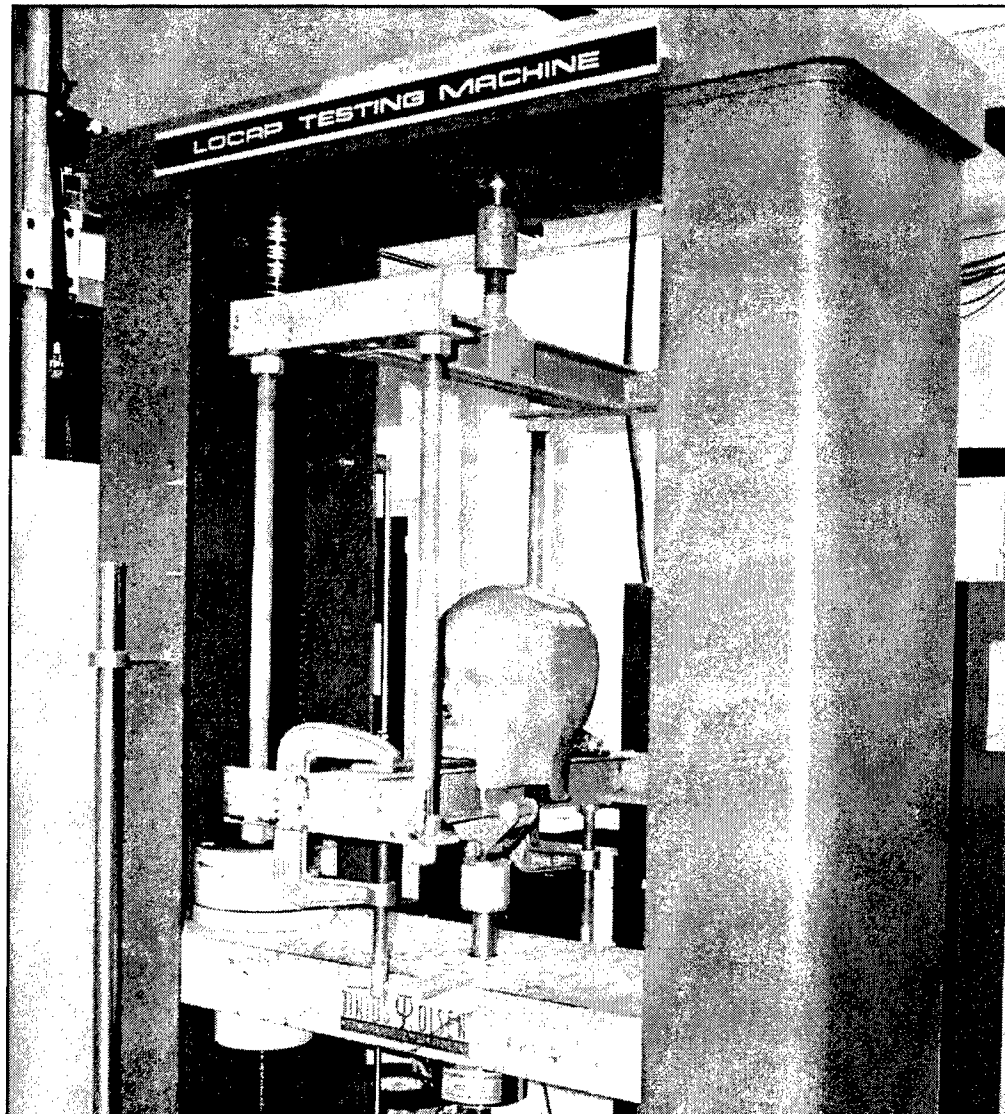


Figure 5. Tinius-Olsen compression/tension apparatus. The headform and simulated chin used during chinstrap elongation tests are shown.

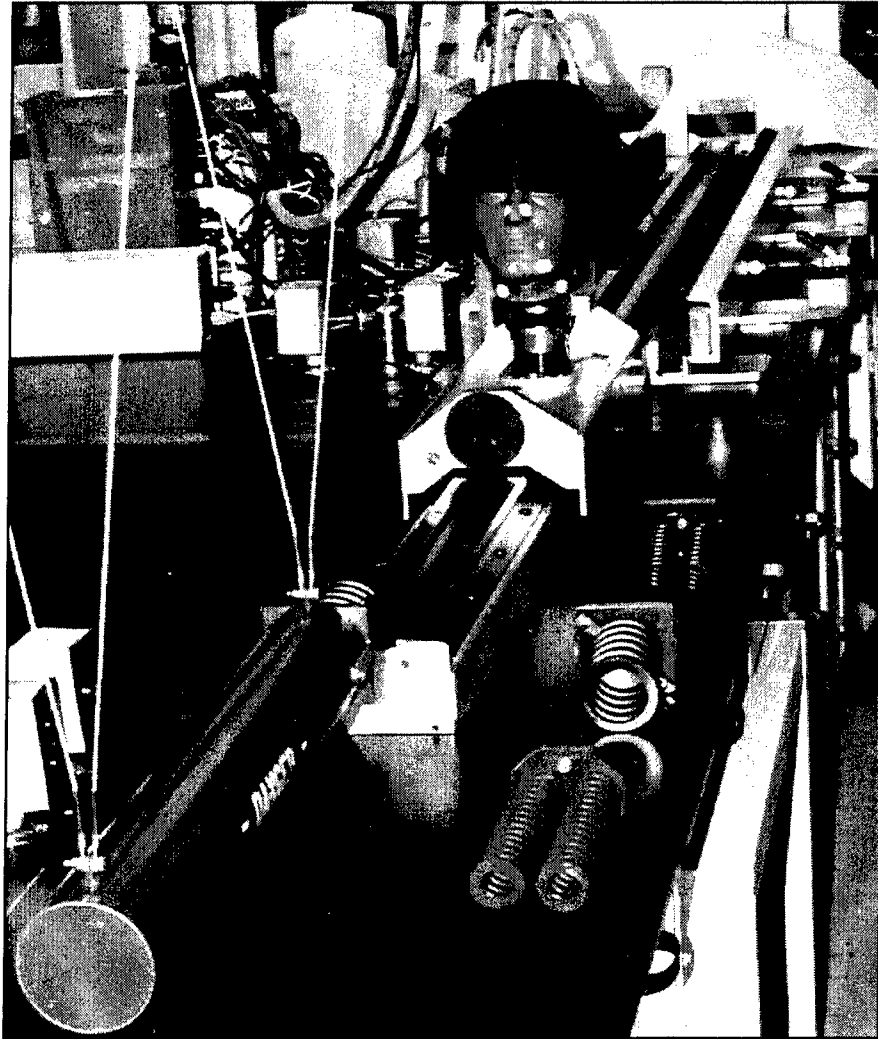


Figure 6. Mini sled test apparatus. Shown in the foreground is the 100-pound pendulum. At the far end of the pendulum is mounted one of four impact interface springs (the three others are shown to the right of the mini sled) used for controlling the sled (carriage) acceleration pulse. The frictional braking system can be seen directly behind the carriage. An HGU-56/P flight helmet can be seen fitted to the Hybrid II headform. The white dots on the headform's nose, chin, and neck are reflective targets used for optically tracking head and helmet motion.

Experimental methods

Dynamic stability

Three new, large HGU-56/P helmets were subjected to dynamic retention testing. As with the static chinstrap elongation evaluation, the retention assemblies in two helmets were replaced with ALPHA buckle and snap-fastener retention assemblies, while a third helmet was left unmodified.

The dynamic retention capabilities of the helmets were assessed at two sled acceleration levels (Figure 7). The "low G" condition exposed the sled to a 26 G half-sine pulse with a resultant 14.56 feet per second (fps) velocity change. The "high G" condition exposed the sled to a 38 G half-sine pulse and produced a 19.33 fps velocity change. These acceleration pulses were applied to the sled and approximated the acceleration level at the C7/T1 spinal vertebra juncture. The 26 G test condition was intended to represent a mild crash or hard landing with the shoulder harness inertia reel locking. The 38 G test condition was representative of a severe but survivable crash and was within the limits of human tolerance. These tests were considered non-destructive, permitting repeated testing of the same helmet assembly.

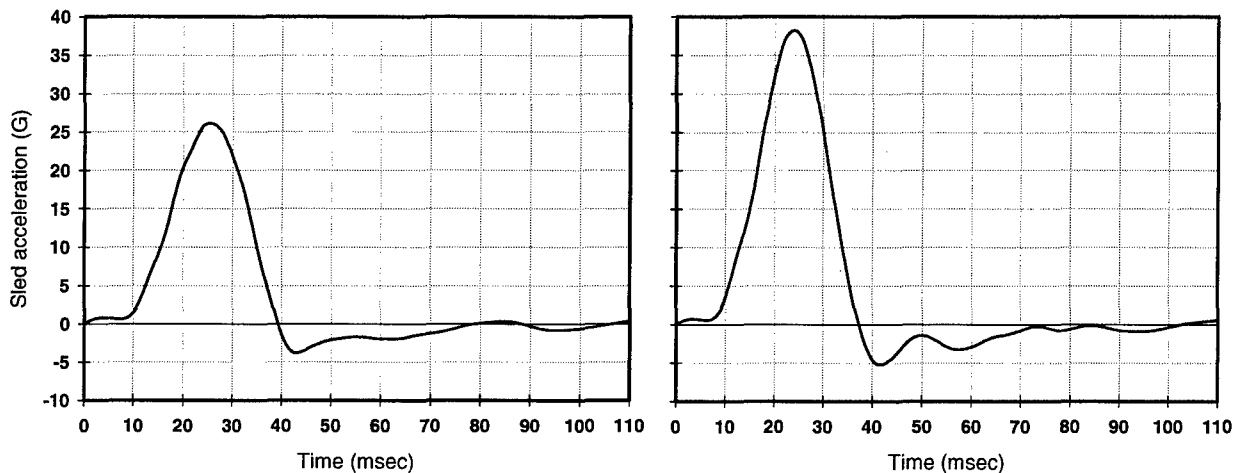


Figure 7. Sample sled impact acceleration time-history traces measured during the dynamic stability trials. Low G trace, 26 G, 14.56 fps velocity change (Left). High G trace, 38 G, 19.33 fps velocity change (Right).

Reflective targets were affixed to the helmets and headform to facilitate tracking helmet motion relative to the headform. A Phantom 5 high-speed video system (recording at 1,000 frames per second) was used to document the dynamic response of the head and helmet assembly. Afterward, helmet motion relative to the Hybrid II headform was tracked optically.

The high-speed video images of each test were digitized. The helmet and head targets were tracked using motion analysis software to obtain the angular displacement of the helmet relative to the test headform.

Static chinstrap elongation

Three medium HGU-56/P helmets were used for this assessment. In two helmets, the standard retention assemblies utilizing the double D-ring buckle were replaced with retention assemblies configured with quick-release ALPHA and snap-fastener buckles, respectively. As a control, the third helmet was left unaltered.

Each helmet was fitted to the test headform and simulated chin shown in Figure 5. The chinstrap elongation tests were performed in accordance with the HGU-56/P production specification (FNS/PD 96-18) (Department of Defense, 1996). A preload of 25 pounds was applied to the chinstrap. Then, the load was increased to 440 pounds and, upon reaching that level, was maintained for two minutes. Chinstrap load versus deflection data were collected at 500 samples per second.

Chinstrap fastener manipulation

Three large HGU-56/P helmets were used in this assessment. As with the static chinstrap elongation evaluation, the retention assemblies in two helmets were replaced with ALPHA buckle and snap-fastener retention assemblies. As a control, the third helmet was left unaltered.

Six Army warrant officer candidates and one Department of the Army Civilian (DAC) aviator voluntarily participated in this evaluation. Participants were collectively briefed as to the nature and impetus for the study. Participants were briefed that each would wear the three helmets described above and would be asked to completely release the chinstrap of each helmet as quickly as possible, using only one hand if possible. Participants were not prohibited from using two hands if needed. All participants were naïve to the use of the quick-release buckles, and were therefore given an opportunity to don the three helmets and practice manipulating the three chinstrap fasteners prior to data collection.

All participants completed three timed chinstrap release trials with each helmet. The three helmets were presented to each participant in a random order. During each trial, participants donned the helmet and adjusted the chinstrap to a comfortable tension. After donning the helmet, participants donned a pair of standard issue Army aviation flight gloves (NSN 8415-01-029-0111) that had been soaked in salt water. Participants started each trial with the chinstrap adjusted comfortably and with their gloved hands in their laps. Timing started when the investigator signaled the participant to begin and ended when the chinstrap had been released and was hanging freely. Between trials, participants submerged their gloved hands in the salt water. Participants completed three trials with each helmet before moving on to the next helmet in the sequence.

This evaluation was determined by the USAARL Institutional Review Board Chairperson to be exempt from the need for obtaining informed consent from the participants (Department of the Army, 1990). Even so, all volunteers were instructed that at any time and for any reason, they could discontinue participation in this study without reprisal.

A Kruskal-Wallis nonparametric ANOVA of ranks was used to determine if a statistically significant difference ($\alpha = 0.05$) existed between the release times for each buckle type. An *a posteriori* Tukey Test was used to make all pairwise comparisons and identify between which buckle types the statistically significant differences existed.

Results

Angular displacements of large HGU-56/P flight helmets configured with the standard, ALPHA buckle, and snap-fastener buckle retention assemblies are shown in Figures 8 and 9 for the 26-G and 38-G acceleration pulses, respectively. Positive displacements represent forward helmet rotation, or rotations in which the brow of the helmet rotates downward, covering the face and nose. Negative displacements represent rearward rotations of the helmet. Peak forward and rearward helmet rotations are shown in Table 1. At both accelerations levels, no clear differences in helmet rotation were seen among the three chinstrap buckles.

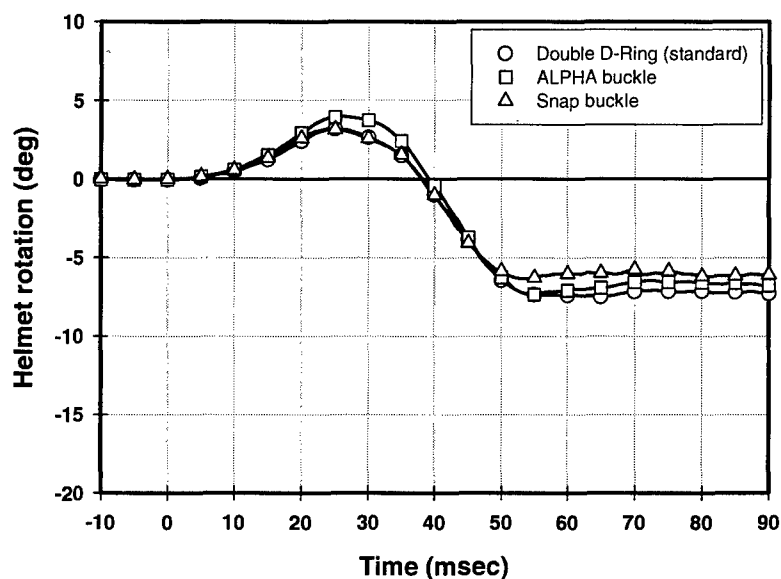


Figure 8. Angular displacement traces resulting from the 26-G dynamic stability testing. Shown are average angular displacement of HGU-56/P flight helmets fitted with double D-ring (standard), ALPHA buckle, and snap-buckle retention assemblies.

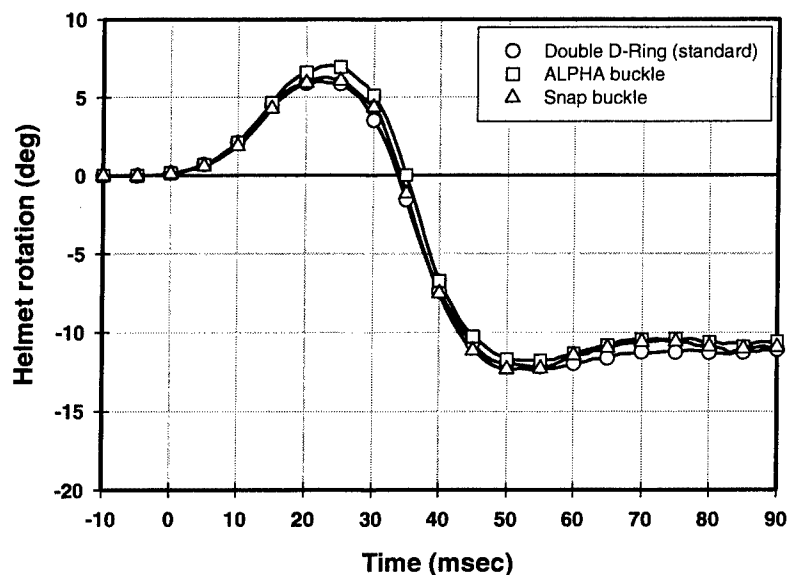


Figure 9. Angular displacement traces resulting from the 38-G dynamic stability testing. Shown are average angular displacement of HGU-56/P flight helmets fitted with double D-ring (standard), ALPHA buckle, and snap-buckle retention assemblies.

Table 1.
Peak forward and rearward helmet rotations.*

	26-G			38-G		
	Double D-ring (standard)	ALPHA buckle	Snap-fastener buckle	Double D-ring (standard)	ALPHA buckle	Snap-fastener buckle
Forward	3.18	3.99	3.24	6.03	7.06	6.29
Rearward	7.52	7.35	6.72	12.29	11.79	12.40

* All rotations are in degrees.

Chinstrap elongation results are presented in Table 2. Total elongation is equal to chin displacement (after 2 minutes at 440 lbs) less chin displacement (at 25 lb pre-load) less the compression of the helmet fitting system and energy-absorbing liner. No helmet exceeded the maximum allowable chinstrap elongation of 1.5 inches (Department of Defense, 1996). Helmets equipped with the two alternate quick-release fasteners performed better (i.e., exhibited less elongation) than the standard helmet during this test.

Table 2.
Retention assembly elongation readings.*

	Double D-Ring (standard)	ALPHA buckle	Snap-fastener buckle
Chin displacement (at 25 lb preload)	0.93	0.71	0.91
Chin displacement (after 2 min at 440 lbs)	2.73	2.31	2.49
TPL and E/A liner compression	0.38	0.26	0.44
Total elongation	1.42	1.34	1.14

*All displacements are in inches.

Individual chinstrap release times for each participant, trial, and chinstrap fastener type are presented in Table 3. Figure 10 shows the average time (\pm one standard error) needed for each participant to fully release chinstraps equipped with the three different buckles. Figure 10 also shows the average release time (\pm one standard error) for all trials with each buckle type. On average, chinstraps equipped with the ALPHA and snap-fastener buckles were released more quickly than chinstraps equipped with the standard double D-ring.

Differences in average buckle release time shown in Figure 10 were statistically significant ($p < 0.001$). Average release times for chinstraps equipped with the ALPHA and snap-fastener buckles were 7.15 and 1.57 seconds, respectively, while the mean release time for chinstraps equipped with the standard double D-ring was 15.81 seconds (Table 3). Between the two quick-release buckles, release times for chinstraps equipped with the snap-fastener were statistically less ($p < 0.05$) than those of chinstraps fitted with the ALPHA buckle (Table 4).

Most participants noted that learning to release the ALPHA buckle quickly would require practice, as it took a "knack" to thread the male portion through the receiver (Figure 3). Five of seven participants disengaged the ALPHA buckle more quickly during their final trial than they did during their first. For these five participants, the average difference in release times was 8.1 seconds (Table 3). This is despite all participants having the opportunity to practice engaging and releasing the ALPHA buckle before their timed sessions.

Observation of the seven participants revealed that all could successfully disengage the both the ALPHA and snap-fastener buckles using one hand while wearing salt water-soaked flight gloves. Participants required only one hand to disengage the snap-fastener buckle in all 21 trials. The same was true in 19 of the 21 trials involving the ALPHA buckle. During two trials with the ALPHA buckle, the male portion of the ALPHA buckle rotated relative to the receiver (Figure 11). Two hands were required to align the male and female portions of the ALPHA buckle and release the chinstrap. The rotation may have been caused by the wet chinstrap slipping through the buckle, releasing tension in the chinstrap. Loss of tension allowed the male portion of the

buckle to rotate relative the receiver. In 9 of 21 trials involving the standard-issue double D-ring, participants required two hands to successfully disengage the buckle.

Table 3.
Chinstrap release times by participant and trial.*

Participant number	Trial number	Chinstrap fastener type		
		Double D-ring	ALPHA buckle	Snap fastener
1	1	15.80	18.00	2.10
	2	12.10	5.90	2.70
	3	16.90	4.75	2.40
2	1	20.10	14.50	1.79
	2	20.82	6.70	1.50
	3	14.87	3.30	2.40
3	1	33.75	14.90	0.90
	2	12.75	2.40	1.10
	3	11.62	2.40	1.00
4	1	8.13	11.90	1.47
	2	3.35	2.22	2.78
	3	6.94	14.63	1.28
5	1	9.90	3.90	1.94
	2	15.60	3.71	1.30
	3	10.56	13.70	0.90
6	1	10.87	3.00	1.00
	2	15.50	5.90	1.03
	3	7.10	2.96	1.00
7	1	18.20	8.10	1.10
	2	26.10	2.70	2.40
	3	41.00	4.60	0.90
All	Mean	15.81	7.15	1.57
	Std. error	1.96	1.12	0.14

* All times are in seconds.

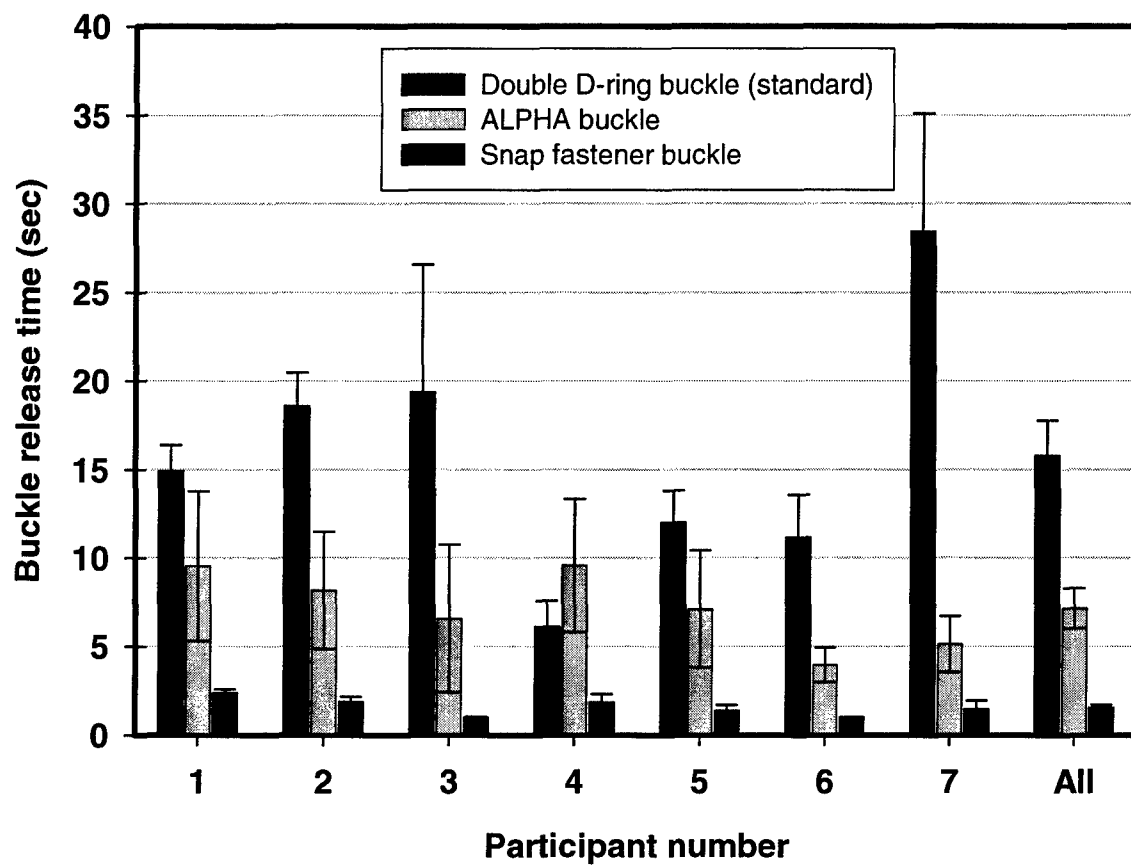


Figure 10. Average individual and group release times (\pm one standard error) by buckle type.

Table 4.
Results of *a posteriori* Tukey Test.

Comaparison	Difference of ranks	q	Significance level (p)
Double D-ring vs. Snap fastener	794.50	9.46	<0.05
Double D-ring vs. ALPHA buckle	306.50	3.65	<0.05
ALPHA buckle vs. Snap fastener	488.00	5.81	<0.05



Figure 11. Male portion of ALPHA buckle rotated relative to receiver.

Discussion

Dynamic retention testing is not a requirement for Army aircrew helmets. However, several documented cases of helmets departing aviator's heads during crashes prompted the USAARL to explore several methods of assessing the dynamic retention capabilities of aircrew helmets (Reading et al., 1984, and Vyrnwy-Jones, Lanoue, and Pritts, 1988), with the mini-sled being the latest and most promising method. No requirements have been proposed as to how much helmet rotation is acceptable, but in general, helmet rotation – forward or rearward – should be minimized, as rotational displacement of the helmet can expose the head, allowing unprotected impacts to occur.

Incorporating either of the two quick-release buckles into the HGU-56/P retention assembly should provide dynamic helmet retention equivalent to that of the current retention assembly configured with the double D-ring buckle. Figures 8 and 9 show no marked differences in the dynamic rotation of HGU-56/P helmets fitted with the alternate retention systems as compared to those of the standard HGU-56/P. Table 1 shows, for the 38-G acceleration pulse, the HGU-56/P helmet equipped with the ALPHA buckle retention assembly rotated 1.03 degrees further

forward than did the standard HGU-56/P flight helmet. This was the largest observed difference in peak helmet rotations.

Overall, chinstrap strength and webbing elongation also play a part in helmet retention. Instances of helmets departing wearers' heads due to chinstrap fasteners failing or being ripped out of the chinstrap webbing under the dynamic loads prompted the introduction of static chinstrap testing into Army aviation helmet specifications. The fabrication specification for the HGU-56/P specifies that the chinstrap should not fail or elongate more than 3.8 cm (1.5 in) when tested as described above (Department of Defense, 1996). Helmets equipped with the two alternate quick-release fasteners meet this requirement and perform slightly better than the standard helmet during this test. As such, use of either quick release buckle should not increase the risk of helmet loss due to chinstrap buckle failure or webbing elongation.

As with the dynamic retention testing, the chinstrap manipulation testing is not a requirement for Army aircrew helmets. However, this evaluation provides an objective means of assessing the speed and ease with which an aviator could remove their helmet in an emergency situation. No firm criteria exist for how quickly an aviator should be able to release their chinstraps, but in general, chinstrap release time should be minimized. From an ease-of-release standpoint, chinstrap buckles should be designed for single-handed operation, due to the possibility of incapacitation during a mishap.

The two candidate quick-release buckles offer better speed and ease of release than does the standard double D-ring. Release times for chinstraps equipped with the ALPHA and snap-fastener buckles were significantly faster than those of the double D-ring (Figure 10 and Table 4). Two hands were needed to successfully release the double D-ring in 9 of 21 trials. In contrast, the snap-fastener buckles were released single-handedly in every trial, and ALPHA buckles were released single-handedly in 19 of 21 trials. Use of either quick-release fastener would improve the speed and ease with which an aviator could release their chinstrap and subsequently remove the HGU-56/P helmet.

One potential hazard of a quick release buckle is inadvertent release. Although the present study did not include any formal assessment of this hazard, no inadvertent releases of either the ALPHA or snap-fastener buckles were observed during these evaluations. In addition, these quick-release buckles have been in use with the British military (ALPHA buckle) and the U.S. Coast Guard (snap-fastener buckle) for several years, with no reported history of inadvertent or unintentional releases.

Conclusions

Incorporating the ALPHA or snap-fastener buckles into the retention assembly of the HGU-56/P flight helmet should not degrade the level of protection (i.e., static and dynamic helmet retention) provided by the HGU-56/P in its current procurement configuration.

Snap-fastener buckles provide superior speed and ease of release than the other two chinstrap fasteners evaluated. As such, the snap-fastener buckle appears to be the best alternative to the standard double D-ring fastener.

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Appendix.

List of manufacturers.

Gentex Corporation
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